

# Precision Measurements for Higgs Physics: How well do we need to know Higgs Couplings?

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# Higgs Boson Couplings

- How well do we need to know Higgs couplings?
  - One approach: As well as possible
- What are largest coupling deviations from SM couplings if we don't see some new state at the LHC?
- Consider several examples:
  - 1 parameter models: Singlet Higgs mixed with SM Higgs
  - 2 parameter models: Composite Higgs
  - Supersymmetry & 2HDMs
  - General effective Lagrangians

# Simplest possibility: 1 parameter

- Universal rescaling of Higgs couplings



- Simplest version of explicit model
  - SM Higgs mixed with electroweak singlet, S

# Higgs Couplings: 1 Parameter

- Singlet,  $S$ , mixed with SM Higgs,  $H_{SM}$ 
  - $S$  could be hidden sector field
  - Communicates to observed sector through Higgs couplings

$$L_{eff} = D_\mu \Phi D^\mu \Phi^\dagger + |D_\mu S|^2 + \mu^2 \Phi \Phi^\dagger + m_S^2 |S|^2 - \lambda(|\Phi \Phi^\dagger|)^2 - \rho S^4 - \kappa (\Phi^\dagger \Phi) S^2$$

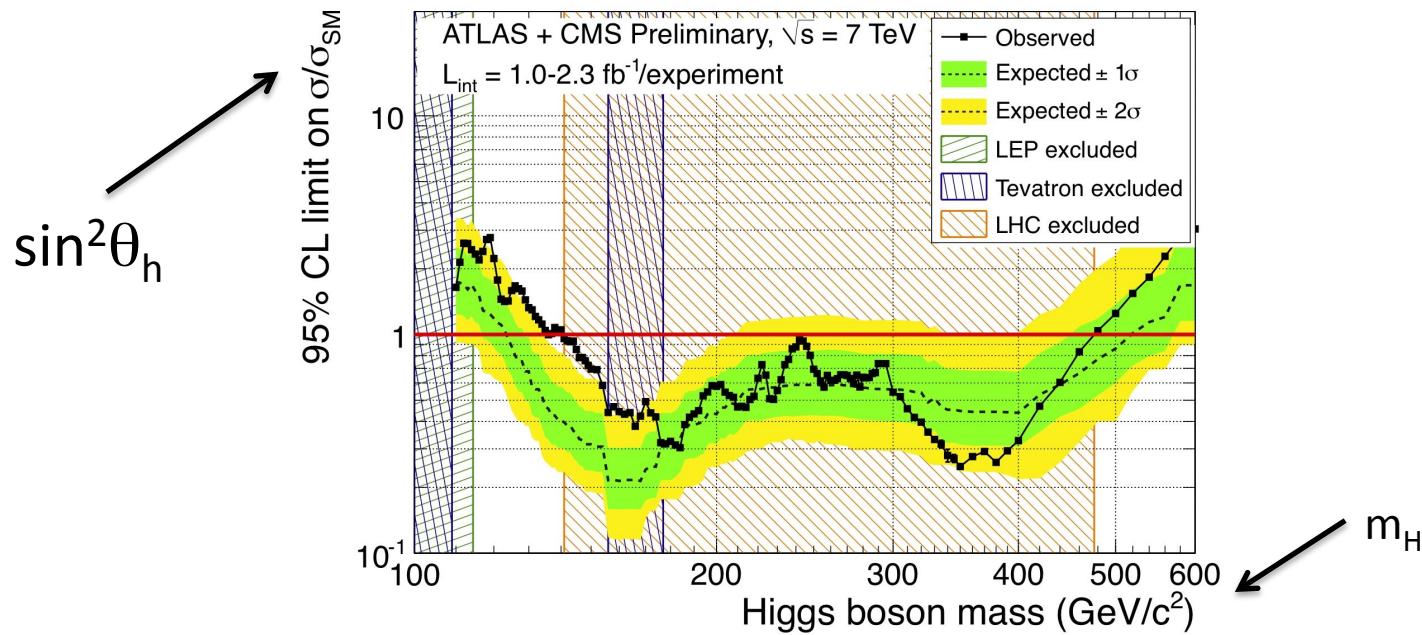
- Physical Higgs:  $h, H$

$$h = \cos \theta_h H_{SM} + \sin \theta_h S$$

$$H = \sin \theta_h H_{SM} - \cos \theta_h S$$

# Higgs Couplings: 1 Parameter

- Higgs couplings modified
$$g_{hXX}^2 = \cos^2 \theta_h (g_{hXX}^{SM})^2, \quad g_{HXX}^2 = \sin^2 \theta_h (g_{hXX}^{SM})^2$$
- If no new decay channels, trivial interpretation of limits

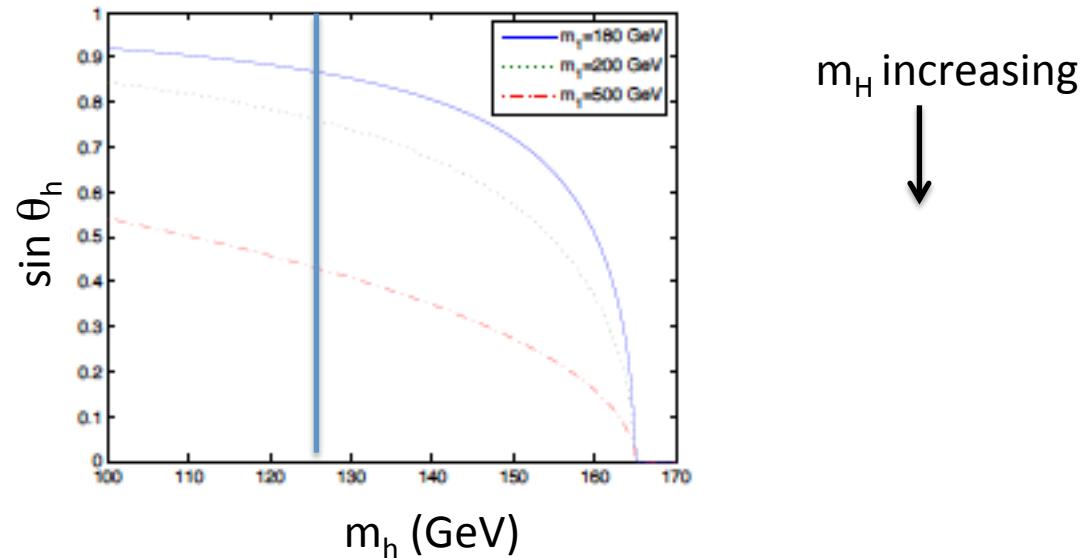


# Higgs Couplings: 1 Parameter

- Modified Higgs couplings affect electroweak precision measurements:

$$\Delta T = (\dots) \cos^2 \theta_h \log(m_h) + (\dots) \sin^2 \theta_h \log(m_H) + \dots$$

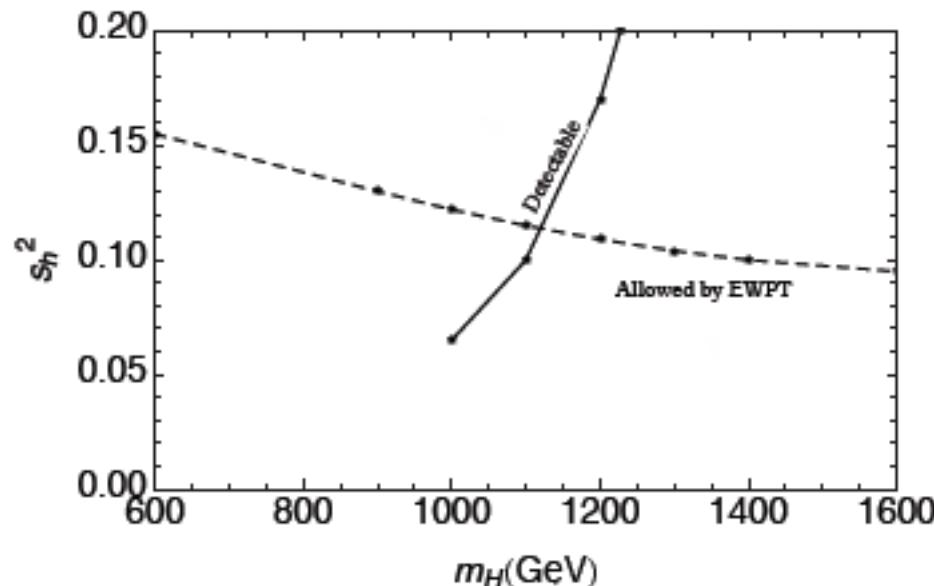
95% CL allowed  
region (from STU) is  
below curves



[Dawson, Yan]

# Higgs Couplings: 1 Parameter

- What is largest  $\sin \theta_h$  such that we won't see H (heavier Higgs) at LHC with  $100 \text{ fb}^{-1}$ ?
  - For  $m_H = 1.1 \text{ TeV}$  expect 13 signal events, 7 background ( $S/\sqrt{B} \sim 5$ )
  - To see new physics (without observing H) need  $\sin \theta_h^2 < .12$



Target precision:

$$\frac{\Delta g_H}{g_H} \sim -\frac{\sin^2 \theta_h}{2} \sim -6\%$$

[Gupta, Rzehak, Wells]

# Higgs Couplings: 2 parameters

- Example: **Composite Models**
- Parameterize by effective operators

$$L_{eff} = \frac{2c_H}{f^2} |\Phi D_\mu \Phi^\dagger|^2 + \frac{c_y}{f^2} \frac{m_f}{v} \left( \Phi^\dagger \Phi \bar{\psi}_L \Phi f_R + h.c. \right)$$

- $\Delta g_{hXX} \sim v^2/f^2 = \zeta^2$

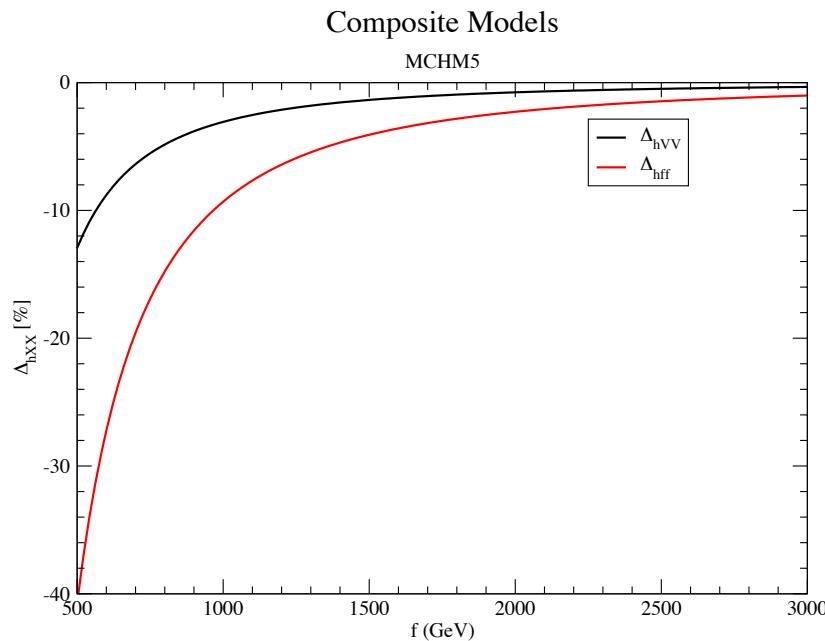
$$\Gamma(h \rightarrow f\bar{f}) = \Gamma(h \rightarrow f\bar{f})_{SM} \left( 1 - \zeta(2c_y + c_H) \right)$$

$$\Gamma(h \rightarrow W^+W^-) = \Gamma(h \rightarrow W^+W^-)_{SM} \left( 1 - \zeta c_H \right)$$

- Precision electroweak measurements restrict  $f$ 
  - Typically  $f_{min} \sim 1$  TeV

# Examples of Composite Models

- Models differ in high scale fermions representations
  - MCFM5:  $1 + \Delta_V = \sqrt{1 - \zeta}$ ,  $1 + \Delta_f = \frac{1 - 2\zeta}{\sqrt{1 - \zeta}}$
  - MCFM4:  $1 + \Delta_V = 1 + \Delta_f = \sqrt{1 - \zeta}$



- 10% measurement of  $\Delta_{hff}$  gets to 1 TeV scale
- 2% measurement gets to 2 TeV

# Higgs Couplings: 2 Parameters

- 2 Higgs Doublet models
  - Parameters are  $\alpha$  (mixing in neutral h),  $\tan \beta$
  - $L = -g_{hii} \frac{m_i}{v} \bar{f}_i f_i h - g_{hVV} \frac{2M_V^2}{v} V_\mu V^\mu h$
  - 4 possibilities for Higgs coupling assignments

	I	II	Lepton Specific	Flipped
$g_{hVV}$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$
$g_{ht\bar{t}}$	$\frac{\cos \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\sin \beta}$
$g_{hb\bar{b}}$	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$
$g_{h\tau^+\tau^-}$	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$\frac{\cos \alpha}{\sin \beta}$

Type II is MSSM – like  
2 Higgs double model

# Decoupling Limit of Type II 2HDMs

Assume  $M_{H^+}, M_A \gg M_Z$

$$\alpha \Delta T \sim \mathcal{O}\left(\frac{M_Z^2}{M_A^2}\right)$$

$$\Delta S \sim \frac{1}{12\pi} \cos^2(\beta - \alpha) \left[ \log\left(\frac{M_A^2}{M_h^2}\right) - \frac{5}{6} \right]$$

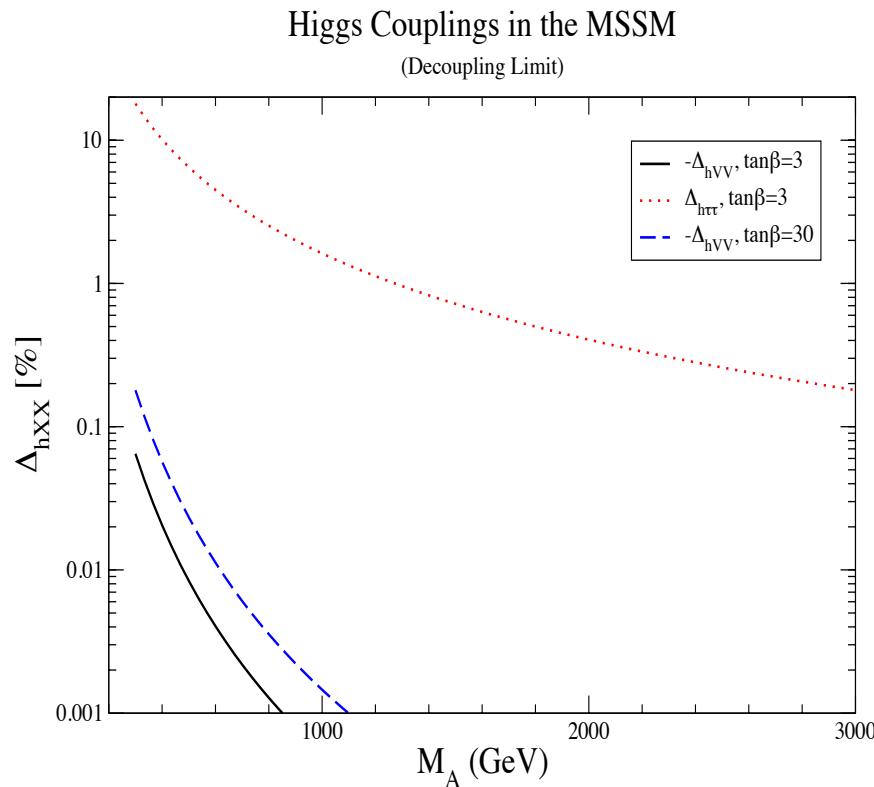
Coupling shifts are small:

$$\Delta_V = -\frac{2M_Z^4 \cot^2 \beta}{M_A^2}$$

$$\Delta_t = -\frac{2M_Z^2 \cot^2 \beta}{M_A^2}$$

$$\Delta_b = \frac{2M_Z^2}{M_A^2}$$

# The world will look SM-Like



- This requires percent level measurements of Higgs couplings to distinguish the 2HDM model from the Standard Model

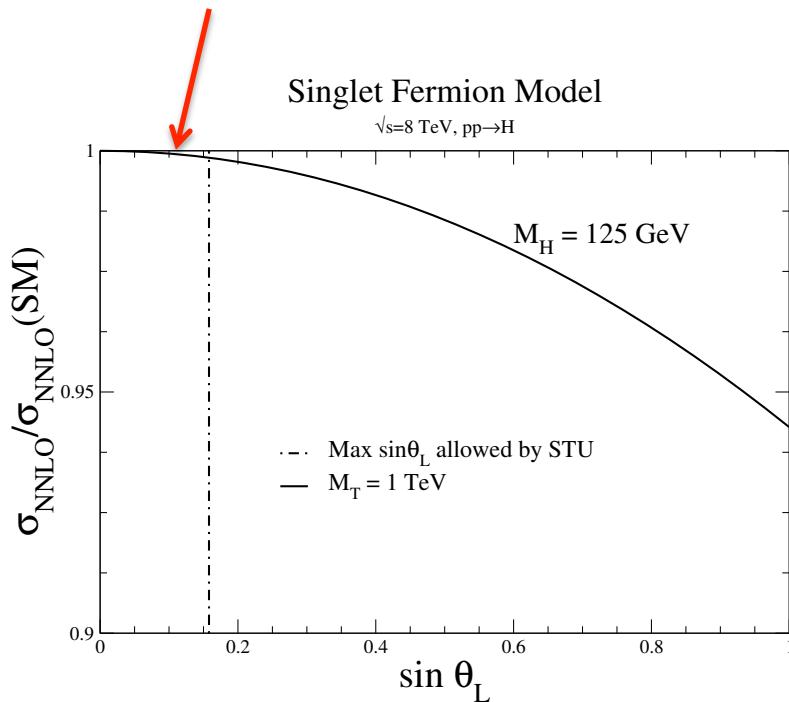
→ If we don't see any new particles, this will be very hard!

# Top Partners: New Charge 2/3 Quark

- Add SU(2) singlet, charge 2/3 quark, T
  - No charge -1/3 quark for to avoid  $Z \rightarrow b\bar{b}$  constraints
- *Motivated by top-color, top-seesaw models, little Higgs*
- Dirac mass for T is allowed

# Top Partners

- Top partner mixes with Standard Model top
- ***Higgs production looks just like Standard Model***
- Parameters restricted by EW precision measurements



$$L \sim c_g \frac{\alpha_s}{12\pi v} h G^{\mu\nu} G_{\mu\nu}$$

Top partners contribute  
to  $c_\gamma$  and  $c_g$ :

$$c_g \sim \mathcal{O}\left(\frac{M_h^2}{M_T^2}\right)$$

# Working Group Goal

- For specific models, find region of parameters allowed by direct searches and EW precision measurements
- Find maximum deviation of Higgs couplings in each model
- Much of this work exists, we just need to put it in a common framework